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An investigation of the relationship between symmetry index in isometric strength and vertical ground reaction forces in drop-landings

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AN INVESTIGATION OF THE RELATIONSHIP BETWEEN SYMMETRY INDEX
IN ISOMETRIC STRENGTH AND VERTICAL GROUND REACTION FORCES IN
DROP-LANDINGS

A Thesis

Presented To

Eastern Washington University

Cheney, WA

In Partial Fulfillment of the Requirements

for the Degree

Master of Science

in Physical Education

By

Lemuel A. Brown

Spring 2012

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Date _____

MASTER'S THESIS

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Chapter I: Introduction

Jumping is an important lower extremity skill used by any individual that takes part in sports that involve explosive movement. Performing this skill successfully requires a person to land properly and without injury. It is often assumed that movements such as landings are symmetrical motions in healthy populations (e.g. Arsenault, Winter, & Marteniuk, 1986). More recent evidence has suggested that seemingly symmetrical bilateral activities like jumps and landings may in fact not be symmetrical (Kernozek, Torry, & Iwasaki, 2008; Kernozek, Torry, Van Hoof, Cowley, & Tanner, 2005; Schot, Bates, & Dufek, 1994). Furthermore, these asymmetrical differences may affect performance in daily activities, work, and sport (Landers, Hunter, Wetzstein, Bamman, & Weinsier, 2001; Lawson, Stephens, Devoe, Reiser, 2006; Lephart, Ferris, Riemann, Myers, & Fu, 2002; Newton et al., 2006; Truckwell, Straker, & Barrett, 2002; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004). Studies have found that strength asymmetries in the lower extremities also exist (Askling, Karlsson, & Thorstensson, 2003; Croisier, Namurois, Vanderthommen, & Crielaard, 2002; Newton et al., 2006; Oshita, & Yano, 2006; Schlitz et al., 2009; Yamamoto, 1993). Other studies have suggested that asymmetry of the lower limbs may be related to injury (Askling et al., 2003; Croisier et al., 2002; Yamamoto, 1993). Few have looked specifically at asymmetrical differences with landing (Ball & Scurr, 2009; Paterno, Myer, Heyl, & Hewett, 2007; Schot et al., 1994). Further, no study has examined both asymmetrical differences in a landing task and bilateral strength differences in the lower extremities. The purpose of this study is to investigate whether there is a relationship between asymmetry in strength and vertical ground reaction forces in drop-landings in healthy

individuals. Asymmetry across these two variables will support that strength differences in the lower extremities may be a potential source of increased injury risk and decreased performance in landing tasks.

Strength is an important physiological characteristic in various functions of daily life. There are data present that show a positive relationship with strength and completing daily tasks (Landers et al., 2001). Strength is essential in the work force as well. In fact, the literature has shown strength to be related to daily job tasks such as bilateral carrying, lifting floor-to-waist, and pushing (Truckwell et al., 2002). Not to mention, strength has high positive relationships with performance in many sports (Davison, Someren, & Jones 2009; Dumke, Pfaffenroth, McBride, & McCauley, 2010; Young, McLean, & Ardagna, 1995), which further can be useful in talent identification (Pearson, Naughton, & Torode, 2006), and monitoring improvements in athletes (Davidson et al., 2009).

More specifically, isometric strength relates to performance in both landings and jumps. One particular study defines strength as the maximal force a muscle can produce at a certain velocity (Knuttgen & Kraemer, 1987). When examining landing most studies used isometric strength that can be defined as maximal voluntary contractions in which the length of the muscle remains constant (Brown & Weir, 2001). There are a limited amount of studies that compare strength with drop-landings (Beutler, Motte, Marshall, Padua, & Boden, 2009; Carcia, Kivlan, & Scibek, 2011; Mizner, Kawaguchi, & Chimelewski, 2008). Beutler et al. (2009) found no significant relationship between strength and the LESS score (a 17-point observation test that evaluates landing technique based on landing errors) however; the researchers compared the relationship of

qualitative data in a landing task to quantitative data in a strength test. Another study by Mizner et al. (2008) also found no significant relationship with strength and vertical ground reaction forces (VGRF's) in landing. Although, their analysis was more focused on investigating the relationship between the change of landing kinetics and kinematics after instructions to isometric strength measures. (Mizner et al., 2008). Overall, there have been very few reported quantitative landing studies investigating isometric strength performance.

One area of focus in the literature with strength in the extremities is bilateral asymmetry. Psuedoseizure and stroke patients are some populations known to exhibit a significant bilateral difference in ground reaction forces and strength (Kim & Eng, 2003; Sackellares, & Sackellares J., 2001). Bilateral symmetry can be described as the balance between two opposing sets of processes (Tomkinson, Popovic, & Martin, 2003). Additionally, a 10% difference in strength testing of the lower extremities is considered a bilateral asymmetry (Bennell et al., 1998; Grace, Sweetser, Nelson, Ydens, & Skipper, 1984; Schlitz et al., 2009; Yoshioka, Nagano, Hay, & Fukashiro, 2010). It is often assumed in the literature that asymmetry may impact performance in both daily activity (Maffiuletti, Bizzini, Wilder, & Munzinger, 2010) and sport (Askling et al., 2005; Croisier et al., 2002; Fousekis, Tsepis, & Vagenas, 2010; Newton et al., 2006). Fousekis et al. (2010) compared lower limb asymmetries of professional soccer players with their training age. Isokinetic testing was used to observe strength asymmetry in three different training age groups: 5-7 years, 8-10 years, and >10 years. The researchers concluded that the least trained players exhibited the highest asymmetries, whereas the most trained professional players had the lowest level of asymmetries. Discovering whether these

populations have a bilateral asymmetry may lead to a training program to reduce the differences between limbs and perhaps enhance performance.

The literature that has examined the relationship between strength asymmetry and injury has been unclear with some studies reporting that strength asymmetry cannot predict injuries (Bennell et al., 1998; Grace et al., 1984; Siqueira, Pelegrini, Fontana, & Greve, 2000) and other studies that have suggested a possible relationship between the two variables (Askling et al., 2005; Croisier et al., 2002; Newton et al., 2006; Potts et al., 2002; Yamamoto, 1993). Bennell et al. (1998) observed both the muscle imbalances and bilateral differences in Australian football players to determine whether lower extremity strength asymmetries could predict injuries across a season with the use of isokinetic tests. The study showed no significant difference in both muscle imbalance and bilateral asymmetry in reference to injury. The authors concluded that isokinetic testing could not discriminate whether players were at risk for injury. In the investigation of bilateral asymmetry, the researchers did not use a symmetry index of relative strength scores for their statistical analysis but rather a comparison of the left hamstring and the right hamstring. This might have affected the statistical results of this study, because most of the literature investigating strength asymmetries have used this method to get reliable results. Yamamoto (1993) observed hamstring strains in track & field athletes and proposed that isometric strength tests may be able to predict athletes that are more susceptible to this particular injury. Knee flexion strength was found to be significantly higher in the non-injured group compared to the injured group. Also, the non-injured group had fewer bilateral asymmetries compared to the injured group, thus showing that isometric strength testing may be a better predictor for bilateral asymmetries in strength

rather than isokinetic testing. Nevertheless, lower extremity strength is an important variable to measure when observing lower extremity injury.

Another key variable to observe when examining the risk of injury is the landing task, which requires proper movement to avoid risk of injury; especially when an individual is participating in a competitive sport (Hauschildt, 2008). Many sports involving landings such as basketball, volleyball, gymnastics, and track require athletes to perform countermovement jumps, dismounts, sprints, and/or falls (Cortes et al., 2007; Lawson et al., 2006; Schlitz et al., 2009; Stephens, Lawson, DeVoe, & Reiser, 2007). Certainly, when athletes land from these movements there are forces associated upon impact known as ground reactions forces (GRFs). These GRFs upon impact can exert up to 14 times the force of the athlete's body weight on the muscles and joints (Panzer, 1987), which unfortunately increases the risk of injury (Gray, Taunton, McKenzie, Clement, McConkey, & Davidson, 1985; McKay, Goldie, Payne, & Oakes, 2001;). McKay et al. (2001) examined the occurrence of injury in thousands of basketball players and found an incidence of 3.85%, landing being the highest contributor to incidence of injury (45%). Another study surveyed female basketball players over a two-and-half year time period and found that landings were implicated in 58% of the injuries (Gray et al., 1985).

Asymmetry in a landing task is present in both healthy, uninjured populations (Schlitz et al., 2009; Schot et al., 1994) and injured populations (Paterno et al., 2007; Schlitz et al., 2009). Schlitz and colleagues (2009) focused on asymmetries with athletes that involve many jump and landing tasks. Research in this study was a between-subjects design that focused on both a group of healthy athletes and a group that had pre-existing

knee injuries. The results showed a significant difference between the lower limbs with a symmetry index greater than 10% and identified the injured population with higher bilateral asymmetries (Schlitz et al., 2009). Schot et al. (1994) collected GRFs to analyze symmetry of joint moments in the lower extremities to adult volunteers that participate in recreational sports. Schot et al. (1994) wanted to evaluate the bilateral variability and found that 80% of the trial differences were predisposed to one side. This suggested that asymmetries in healthy populations do exist. A study has yet to examine the relationship between asymmetries of drop-landing and isometric strength, and thus requires further investigation.

Statement of the Problem

This study served to a) investigate the relationship between symmetry in isometric strength and vertical GRF's in drop-landings and b) analyzed the differences between the dominant and non-dominant limbs in both isometric strength and vertical ground reaction forces.

Delimitations, Limitations, Assumptions

Much of the research has used homogenous sport populations ranging from amateur to professional athletes to investigate asymmetries in drop-landings or maximal strength (Bennell et al., 1998; Grace et al., 1984; Schlitz et al., 2009). This study delimited the population to both healthy males and females participating in at least three hours of activities per week that involve jumping (Kernozek et al., 2005; Kernozek et al., 2008). All individuals participating in the study must not have previous injuries in the lower extremity, because significant differences between injured and non-injured

populations with regard to symmetry have been demonstrated (Croisier et al., 2002; Schlitz et al., 2009; Yamamoto, 1993). Studies involving symmetry have used both isokinetic testing (Askling et al., 2003; Bennell et al., 1998; Croisier et al., 2002; Grace, 1984; Newton et al., 2006; Siqueira et al., 2002) and isometric testing (Oshita & Yano, 2010; Yamamoto 1993). The studies involving isokinetic testing were interested in unilateral muscle imbalances, which is not a part of our research and thus, this study was delimited to maximal voluntary isometric contraction of the lower extremities. Another regulation to the study is that subjects were instructed to land in their typical manner as if they were landing from a jump. Thus, there were limitations on the control of each individual's landing mechanics (Cortes, 2007).

Previous research has found asymmetry in healthy adults; as a result, it was assumed that this study would also find asymmetries in landing as well (Schot et al., 1994). Subjects were involved in testing where maximal effort will be required. Thus, it was assumed that subjects followed our instructions by not participating in any fatiguing activities in the hours before the study. An assumption was also made that each subject was exerting maximum effort in each trial of the isometric leg press and that each landing performance accurately represented what is 'typical' for that subject.

Hypotheses

The purpose of this study was to determine if there was a relationship between asymmetries in ground reaction forces in drop-landings and isometric strength performance in a population of healthy adults. The following null hypotheses was tested in this investigation. There is no significant relationship between symmetry index calculated from an isometric leg press task and the symmetry index associated with

vertical ground reaction forces during a drop-landing task. Additionally, it was hypothesized that leg dominance is not related to asymmetry in the temporal characteristics of the impact during a drop-landing task.

Significance

No research has investigated the relationship between the asymmetry found in drop-landing of healthy adults with isometric strength between the lower limbs. It has been hypothesized that symmetrical landing can improve performance and reduce the chance of injury in sport (Gray et al., 1985; Hortia et al., 2002; Lawson et al., 2006; Lephart et al., 2002; McKay et al., 2001; Wisloff et al., 2004). If the results of the study demonstrate a significant relationship between strength asymmetry and GRFs in drop-landing, then assessing strength asymmetries and creating training interventions aimed to reduce bilateral asymmetries as a means of improving performance and reducing injury in landings can be approached by professionals. If the study shows no significant relationship between the dependent and independent variable then the asymmetries found in landing may be related to factors other than strength.

CHAPTER II: Review of Literature

Landing from a jump in certain activities such as sport is a crucial task that may affect performance in individuals. It is assumed that many non-contact injuries have occurred due to improper landing criterion. Previous areas of research in the past decade have mainly focused on the kinetics and kinematics of the lower extremity. However, very few studies have tested the relationship between lower body strength and landing mechanics in healthy individuals. This review of literature will serve purpose to a) evaluate the importance of lower extremity strength in performance tasks and training programs b) examine the relationship bilateral asymmetries in strength and landing.

Strength

Lower extremity strength is an important characteristic in performance and has shown to improve daily tasks (Landers et al., 2001). Landers et al. (2001) reviewed the strength relationship through the stand-sit test because many daily activities that are completed everyday involve the motion of sitting and standing from a chair. Older and younger women were compared in both strength and the stand-sit tests and the younger women were found to be stronger and faster in the stand-sit test. The researchers proposed that lower extremity strength is related to the stand-sit task because it involves the knee extensor muscles.

Strength in the lower extremity is just as important in sport. Dumke et al. (2010) studied the relationship between strength and running economy in runners. A correlation of $r = .57, p = .05$ was found between runners in peak isometric strength and the VO_2 maximum test. Jumping is another task involved in many sports that has shown to be related to strength. Wisloff et al. (2004) examined the relationship with maximum squat

and jumping height in elite level soccer players. The researchers found a value of $r = 0.78$, $p < 0.02$ that demonstrated a high positive correlation between the two variables. Wisloff et al. (2004) suggested that a higher maximal strength value would result into more powerful jumps. Impellirezzi et al. (2007) also found a high positive correlation with vertical jump and strength ($r = .083$, $p < 0.001$), but in athletes that participate in sports other than soccer. Certainly, strength influences an individual's ability to perform important sport tasks.

It is unclear in the literature whether there is a relationship between lower extremity strength and landing. Lephart and colleagues (2002) examined strength and landing across male and female basketball, volleyball, and soccer players. The researchers found a significant difference in strength values at knee flexion and lower leg internal rotation (Lephart et al., 2002). Their data supported that males had better landing skills than females. Lephart et al. (2002) also reported that the female athletes were weaker than the male population and thus, the researchers concluded that poor landing skills might be related to muscle weakness. More recent research reviewed muscle strength in the lower extremity with landing in female athletes and found no significant relationship between both isometric strength and landing (Mizner et al., 2007). Mizner et al. (2007) disputed the previous claims that poor landing was related to muscle weakness, however their theory was based on a within-subject design rather than a between-subjects design in the previous study. Additionally, the researchers were associating an open kinetic chain test with a closed chain movement. Overall, Mizner et al. (2007) failed to find any quantifiable data supporting a relationship between strength and landing. Buetler et al. (2009) also examined the relationship between strength and landing, but in

military cadets. Their testing procedures involved an isokinetic dynamometer with visual inspection of landing. Their data suggested that there was also no relationship with lower extremity strength through a mix quantitative-qualitative research design. Carcia and colleagues (2011) examined the relationship between landing and isometric leg press. They hypothesized that if they used a closed kinetic chain test with a closed chain movement that there would be evidence relating both lower extremity strength and landing. There was no significant relationship found between isometric strength and landing, but the researchers theorized that if they used a more functional strength test that represented a landing they would find more clear results (Carcia et al., 2011). The relationship between landing and strength has been under researched and is still unclear whether there are relationships between strength and landing, but strength in other movement tasks that are similar to landings such as jumping have shown strong positive relationships.

Lower Extremity Symmetry

When referring to lower extremity symmetry it is essential to understand the innate differences in leg dominance. It is established in the literature that an individual's dominant leg is the preferred leg to kick a ball (Previc, 1991). Previc (1991) traced the origins of leg dominance from prenatal development. The general theory on cerebral lateralization (two halves of the brain) is that peripheral dominance is determined from the central nervous system, which affects peripheral dominance in the extremities (Previc, 1991). This perspective on leg dominance agrees that neuromuscular development is the key factor of the dominant leg in the lower extremities. Gabbard & Hart (1996) reviewed the three most popular explanations of how to define leg

dominance, two of which are cited most in the field of symmetry. The two theories are based on stabilization theory and Previc's mobility theory mentioned earlier. The stabilization theory believes that the more dominant leg is the postural leg that stabilizes the body as the non-dominant leg performs a muscle action. Gabbard & Hart (1996) concluded that the more acceptable theory for explaining leg dominance is Previc's theory, although more research should clear up this area. The most recent studies on symmetry of lower extremities agree with the previous notion of Previc's mobility theory (Lawson et al., 2006; Oshita & Yano, 2006; Schlitz et al., 2009; Stephens et al., 2007). Nevertheless, many studies investigating asymmetry with strength will take leg dominance into account when considering asymmetrical differences (Askling et al., 2002; Bennell et al., 1998; Croisier et al., 2002; Grace et al., 1984; Newton et al., 2006; Yamamoto et al., 1993).

Lower extremity bilateral asymmetries have been identified within isometric strength studies in both healthy and injured populations. In the literature, a 10% difference in strength testing of the lower extremities is considered a bilateral asymmetry (Bennell et al., 1998; Grace et al., 1984; Schlitz et al., 2009; Yoshioka et al., 2010). Oshita and Yano (2010) examined asymmetry of the lower limbs at low intensity isometric contraction. Strength of each leg was tested at voluntary contraction at 10%, 20% and 30%. Significant results were only observed at 30% isometric contraction. Oshita and Yano's (2010) results were consistent with other studies because the asymmetries increased with contraction intensity. This is because at very low intensities variability between the lower limbs is too small to exhibit a symmetrical difference (Oshita & Yano, 2010). Yamamoto (1993) was able to find asymmetries of the lower

extremities in both healthy and injured athletes. The subjects in both groups range from 7-14% according to the symmetry index. Surely, there are bilateral asymmetries present in both populations when using isometric testing.

Controversies whether or not asymmetry increases injuries and reduces performance are still present in the literature. Bennell and colleagues (1998) examined bilateral asymmetries in football players with isokinetic testing. Their analyses consisted of t-tests to determine whether there was a difference in leg dominance, leg condition, and injured vs. non-injured populations. Bennell et al. (1998) found no significant differences between dominant and non-dominant legs, injured leg vs. non-injured leg, and injured athletes vs. non-injured athletes. They concluded that bilateral asymmetry could not predict injury in sports. However, they did not use a symmetry index to determine a 10% in their comparison, but rather raw values from paired t-tests and independent t-tests. Grace and colleagues (1984) calculated bilateral strength asymmetries with a symmetry index in their athletic population. They used a between-subjects design to examine asymmetries of an injured and non-injured group. They did find that 1 of 3 players had an asymmetry according to the 10% definition, but could not find a significant difference between the injured athletes and non-injured athletes. Grace et al. (1984) also agreed that a strength asymmetry could not predict risk of injury. Their conclusion was based on a much younger population from 13-18 yrs old, which is a different population in all other isokinetic strength asymmetry studies that have used adults.

Other studies found that bilateral asymmetries affect performance in sport tasks (Newton et al., 2006; Yamamoto, 1993). Newton et al. (2006) compared dominant and

non-dominant legs of softball players using a symmetry index in squats, single-leg jump, isokinetic, and 5-hop tests. They found significant differences in all, but single-leg jumps. Newton et al. (2006) disagreed with previous studies and suggested that perhaps their population found bilateral asymmetries because softball is a more asymmetrical sport compared to other sports. Previously mentioned Yamamoto (1993) discovered a significant difference between hip flexion and knee extension of the lower extremities. Further, when comparing the healthy population to the injured population there were significant asymmetrical differences between isometric hip flexion and knee extension supporting the idea that asymmetries are greater in injured populations than healthy populations. The hamstrings are a group of muscles that work against these movements. Yamamoto (1993) suggested that bilateral imbalances were higher in the injured populations because bilateral asymmetry increased the load on the hamstring muscles leading towards hamstring strain. Out of all of the studies that analyzed the difference between the right and left extremity and bilateral asymmetry, three of the four used a strength index. One of the three studies found no significant difference, but they were observing adolescent populations (Grace et al., 1984). The other two studies that used a strength index supported the presence of significant differences in bilateral asymmetry and concluded that these asymmetries lead to a reduction in performance and an increase to injury (Newton et al., 2006; Yamamoto, 1993). The inconsistency between Yamamoto (1993), Newton et al. (2006), and Grace (1984) could be an issue of statistical analysis, population, and/or isokinetic testing.

It has been hypothesized that the most trained athletes exhibit the least strength asymmetry and thus, have a higher level of performance than their lesser-trained

counterparts. Fousekis and colleagues (2010) examined three different professional soccer player groups that were determined by training age. The study reported an inverse relationship between professional training age and asymmetry (Fousekis et al., 2010). The researchers concluded that the reduction of strength asymmetry in long-term training could have been due to an improvement in neuromuscular system over time. Perhaps, sport training may reduce asymmetry and improve performance.

Training programs tailored to reduce strength unilateral asymmetries have been described in the literature. Askling and colleagues (2002) hypothesized that enlisting athletes in a pre-season training program that focused on strengthening the hamstrings may reduce the occurrence of hamstring injuries in-season. The researchers randomly divided athletes into two groups, one group was put into the training program and the other group did not train. Askling et al. (2002) discovered a significant difference between eccentric and concentric knee flexor strength as well as a significantly lower number of hamstring occurrences in the pre-season training group. The researchers suggested that hamstring training for the preseason is a valuable technique to reduce injury and improve performance. It is evident that trainers can create programs to reduce unilateral strength asymmetries and if relationships between strength and landing are significant future studies can experiment with interventions aimed to reduce bilateral asymmetry.

Landing

Landing is an important task seen in sports, which has high associated injury risk. McKay and colleagues (2001) observed the injury rates of over 10,000 basketball players over one competitive season. The results showed 3.85 injuries per 1,000 subjects, 45% of

the injuries occurred during landing, and almost half the injured players missed a week or more of competition (McKay et al., 2001). McKay et al. (2001) attributed the high percentage of landing injuries to the frequency of jumping and landing involved in basketball and suggested that players must learn better strategies for landing. Landing is essential in sport and must be further studied for reducing injury.

Research involving drop-landings has shown that asymmetries exist in the lower extremities of healthy individuals (Schot et al., 1994). Schot et al. (1994) examined the bilateral asymmetries in 10 subjects over 25 trials of drop-landing. They discovered select kinetic bilateral asymmetries in all subjects. The majority of subjects had more than two kinetic asymmetries with landing (Schot et al., 1994). Clearly, bilateral asymmetries in drop-landing exist in healthy populations.

An area that receives much focus in biomechanics research is the observed sex difference associated with landings. Decker et al. (2003) conducted a between-subjects design reviewing kinetics, kinematics, VGRF's and energy absorption in males and females. They observed that females generally landed more erect than males. This study found that females extended their knees and ankles by adding more load to the plantar-flexor muscles, but found no differences in VGRF's (Decker et al., 2003). Kernozek and colleagues (2005) observed kinematic and VGRF comparisons in males and females as well, and they found females had more ankle dorsiflexion rather than ankle plantar flexion compared to the male population. They also found no differences between the sexes on VGRFs. The researchers implied that the increase in ankle range of motion may be another approach to absorb energy from the landing by reducing the load on the knee.

Overall, all studies demonstrated some sort of kinematic difference, even though no VGRF's are distinguished between the sexes.

Screening for improper landings have become a popular tool that is used in sport and research. Beutler et al. (2009) used the Landing Error Scoring System (LESS) to examine landing techniques with military cadets. The LESS is a 17-point questionnaire that describes the kinematics of landing and is used to qualitatively evaluate subjects' landing technique. Each point is considered to be an error in landing. Hauschildt (2008) determined another approach examining landing, but he examined ipsilateral asymmetry (agonist-antagonist asymmetry). He proposed that there are two types of landings: quadriceps dominant and gluteus dominant, which are determined depending on agonist-antagonist strength ratio. The athletes that have unilateral muscle imbalances exhibit a quadriceps dominant landing, which puts a large load on the anterior cruciate ligament (ACL). Hauschildt (2008) contributed many key tips to train individuals how to land properly as well as compiling exercises to improve landing mechanics. In conclusion, screening methods for proper landing have been created for both kinematics and unilateral asymmetry, yet no screening methods have been developed to for bilateral asymmetry.

Summary

Strength is related to many performance tasks in sports and possibly in landing. Bilateral asymmetries are observed in both injured and non-injured populations for both strength and peak VGRF's in landing. Landing tasks may be associated with risk of injury in both males and females. Studies involving training have shown to help athletes to improve their bilateral strength asymmetries and their asymmetries in landing. No

study has investigated the relationship between the two. If the asymmetries in strength and VGRFs in landing have a significant relationship then strength coaches can screen athletes to identify lower leg strength asymmetries, and perhaps further research can be conducted to determine if improving asymmetries in strength can reduce injury incidence and benefit performance.

CHAPTER III: Methods

The purpose of this study was to investigate the relationship between asymmetries in ground reaction forces in drop-landings and isometric strength performance in healthy adults. In the past it was assumed that landing from a jump was a symmetrical task (Arensault et al., 1983). However, recent studies have discovered variations between limbs for several variables (Askling et al., 2003; Croisier et al., 2002; Newton et al., 2006). This chapter will explain the equipment that was used and the procedures that were followed for this study.

Subjects

Subjects participating in this study consisted of a minimum of fourteen healthy males and females ages 18 yrs and older. Because no study has been done examining the relationship between isometric strength and peak VGRFs in bilateral drop-landings, four of the closest studies involving these variables were chosen to examine subject size (Christiansen & Stevens-Lapsley, 2009; Impellizzeri et al., 2007; Kim & Eng, 2003; Schot et al., 1994). Three of the studies investigated relationships using either a Pearson or Spearman correlation and were put into sampling calculator that found the required sample size for testing zero population correlation null hypothesis with 5% type-I and 10% type-II errors (<http://home.ubalt.edu/ntsbarsh/Business-stat/otherapplets/SampleSize.htm#rcorrelation>). Schot et al. (1994) had 10 subjects, 5 females and 5 males participate in their drop-landing study investigating bilateral asymmetry. Christiansen and Stevens-Lapsley (2009) had a subject number of 25 for their research on the relationship between lower limb asymmetry and knee function. In their analysis they found a value of $r = 0.49$, $p < 0.05$ between VGRF's and strength

asymmetry, and their study gave a suggested sample number of 31 from the sampling calculator. Kim and Eng (2002) had 28 subjects and their correlation between the symmetry index and GRF's was $r = 0.586$, $p < 0.05$ for their study on symmetry in VGRF's. The correlation value was entered into the sampling calculator and the recommended subject number was 21. A study investigating the relationship on bilateral asymmetry with a vertical jump test had 41 subjects (Impellizzeri et al., 2007). Their significant correlation result of $r = 0.83$ was inputted in the sampling calculator and 9 subjects were suggested for the population size. The range of voluntary subjects in all of the studies involving asymmetry with strength and/or GRFs in drop-landing was from $n = 10$ -41. (Christiansen & Stevens-Lapsley, 2009; Impellizzeri et al., 2007; Kim & Eng, 2003; Schot et al., 1994). The sampling calculator gave a suggested sample size from 9-31. The large range of subject number in both subject number and recommended sample size could be due to the slight differences in testing procedures. Because of the wide range in suggested subject number, our study recruited over fourteen voluntary subjects equally spread between sex.

Consent form guidelines were followed by the Eastern Washington University Institutional Review Board (IRB) for the use of human subjects. A healthy individual for this study was defined as someone who has had no self-reported previous injuries of the lower extremity, and participates in at least 3 hrs per week of physical activity that includes jumping and landing tasks (Kernozek et al., 2005; Kernozek et al., 2008). Subjects were recruited on a voluntary basis from class announcements that took place on Eastern Washington University campus. Additionally, word-of-mouth and referral

methods were also used to ensure a subject count of at least ($n = 14$) for the research study.

Equipment and Instrumentation

Strength Test. Force plates were used to measure the dependent variables for the study. A uniaxis Pasco™ force plate (Roseville, CA) was used to obtain maximal voluntary isometric contraction of the lower extremities. The Pasco™ force plate has been tested previously for reliability and validity requirements and has been found to be acceptable in both areas (Dunlavy et al., 2007). The force plate for the leg press was attached to bars mounted on the wall that was adjustable to the subject's foot height (Impellizzeri et al., 2007). The subject was seated in a Systems 3™ Biodex (Tempe, AZ) facing the wall of the force plate. The distance between the force plate and subject on the chair was adjusted to achieve a knee angle of 60° as measured by a Baseline™ plastic goniometer (White Plains, NY) (see Figure 1). DataStudio™ software (Roseville, CA) was used in conjunction with the uniaxis force plate for data collection of maximal force in Newtons (N) at a sampling rate of 100 Hz (Akagi et al., 2008; Impellizzeri et al., 2007).

Drop-landing. Two 2-axis Pasco™ force plates (Roseville, CA) were used to collect the GRFs of the lower extremities in the drop-landing. Ground reaction forces from the landing were collected using DataStudio™. The sample rate of the force plates was set for 1000 Hz (Schot et al., 1994).



Figure 1. Mounted uniaxis force plate for maximal voluntary isometric contraction test

Procedures

The subjects involved with this study participated in two days of testing. The first day allowed the subjects to become familiarized with the procedures and allowed the investigators to collect descriptive information on the subject. Subjects handed in their signed consent form before participating in any testing or warm-up procedure. The second day the subjects participated in the strength and drop-landing tests after a low intensity warm-up. Data were collected on the second day of testing.

Familiarization day.

Warm up. On day one of testing the investigator collected descriptive data from the subject including height (cm), weight (lbs), age (months) leg dominance, and physical activity level. All data was recorded on a Microsoft Excel™ spreadsheet (Redmond, WA). A Harpenden™ pocket stadiometer (Crymmych, Wales) was used to measure the height in centimeters (cm) of each subject. Each subject's weight (lbs) was retrieved by a force plate and collected via DataStudio™ (Roseville, CA). To determine the dominant leg the subject filled out a questionnaire (refer to the Appendix). A Monark™ cycle ergometer (Varberg, Sweden) was used for the warm-up portion of the study. The resistance for the cycle ergometer was set at a low intensity (.5-1kp) for an adequate warm-up that would not exhaust the subject, but would increase blood flow, core body temperature, and reduce the potential of injury (Bompa & Haff, 2009; Carcia et al., 2011; Mizner et al., 2008). Following the bike warm-up the subjects participated in a number of dynamic exercises. An investigator lead the subjects into a series of dynamic exercises from a low to medium intensity (Bachle & Earle, 2008). The starting point was at the

beginning of a 6 m tape measure that was taped on the floor. The subjects performed low intensity exercises such as quadriceps pulls and hamstring hugs in a down and back motion (12 m). Butt kicks, carioca, and A-skips are medium intensity exercises that were performed in a down and back motion twice (24 m). All exercises were demonstrated by the investigator and lasted no longer than 5 mins.

Vertical jump test. The maximum vertical jump height of each subject was assessed using a Sports Imports™ Vertec (Hillard, OH). The investigator verbalized the standard procedures of the vertical jump test from Baechle and Earle (2008). The subjects participated in three trials (Baechle & Earle, 2008) to familiarize him or herself with the test. If for any reason a subject needed to take more practice trials they were able to do so. The subjects had 1 min of rest between each trial (Wisloff et al., 2004). All subjects' standing reach heights were measured to be used in the calculation of jump height. Additionally, all subjects' reach heights were measured with heels off the ground and then added to 30 cm to get each subject's drop height.

Isometric strength. After the vertical jump test the subjects were seated on a Biodex chair and their knee angle of the right leg was measured with a Baseline™ plastic goniometer from 60° of flexion at the knee (Reinking, Bockrath-Pugliese, Worrell, Kegerreis, Miller-Sayers & Farr, 1996). All subjects were asked if they had any questions about the procedure for the isometric leg press. The right leg was chosen for all subjects, because it is more accessible in getting the knee angle from the Baseline™ plastic goniometer on the Systems 3™ Biodex. The reference bony landmarks were the lateral epicondyle of the femur and the lateral malleolous (James, Sizer, Starch, Lockhart, &

Slaterbeck, 2004; Reinking, et al., 1996). The subjects were instructed to push submaximally on the command “go”. During this 5 s time frame the subject progressively pushed harder, until the command "push to max" is given (Chaffin, 1975). All subjects held maximal force no longer than 5 s and then steadily declined to rest (Blazevich, Gill, & Newton, 2002). Verbal encouragement was given to the subjects during maximal voluntary contraction. Testing was alternated between the right and left leg until 5 trials for each were collected (Zeh et al., 1986).

Drop-landing. Subjects performed drop-landings from gymnastic rings hung by steel cables from ceiling I-beams. The length of the rings were leveled and adjusted so that each subject would drop from 30 cm distance from their toes to the force plate. The investigator verbally instructed each subject to step up onto a box and reach forward and overhead to grasp the rings, one for each hand. Then the investigator instructed each subject to step off the box to hang from their hands. The investigator stopped any horizontal swinging motion that was observed and made sure that the two force plates were underneath each subjects' feet. All subjects would let go of the gymnastic rings once the investigator gave the command ‘drop’ (Ball & Scurr, 2009; Carcia et al., 2011). Each subject was instructed to land with their hands on their waist to try and eliminate any influence from the upper body for the drop-landing protocol.

Testing day. All procedures that subjects experienced on the familiarization day starting with the warm-up were almost identical to the testing day. No vertical jump test was measured on testing day, because the data were previously collected on the familiarization day. For the isometric leg press test the subjects’ first leg to perform the

maximal strength test was block-randomized in the study. There was a rest period of 1 min between each trial on each leg (Newton et al., 2006). Testing was alternated between the right and left legs until 3 trials for each leg were collected (Impellizzeri et al., 2007). The tare function on the force plate was utilized following each trial to account for the possibility of drift in the signal. For the drop-landing test all subjects were given 30 s of rest between all three trials (Ball & Scurr, 2009).

Analysis

All statistical analyses were completed with Statistical Package for the Social Sciences™ Version 14 (SPSS Inc., Chicago, IL). Maximal isometric peak force were determined by averaging 3 s of the plateau in maximum voluntary contraction (Chaffin, 1975).

Symmetry indices (SI) were calculated for isometric strength and peak VGRFs using the following equation (Kim & Eng, 2003):

$$SI (\%) = \frac{D_{leg} - ND_{leg}}{D_{leg}} \times 100$$

where D_{leg} is the dominant leg and ND_{leg} is the non-dominant leg as determined by the leg with which subjects indicated they would kick a ball. The trials data for the absolute value symmetry index were tested for trends using one-way ANOVAs, and for internal consistency reliability using Cronbach's alpha coefficient. The mean of the trend-free trials were used in all subsequent analyses (Henry, 1967). Prior to conducting analyses for the research hypotheses, symmetry index variables for isometric leg press and peak VGRF were evaluated for an effect of sex using independent t-tests. No significant effect of sex was found for either variable, thus all subsequent analyses were collapsed across sex. To determine if significant asymmetry exists for lower extremity isometric strength

and peak VGRFs during landing, one-sample t-tests were used comparing the absolute value symmetry index for each variable to a value of zero (indicating symmetry or equivalence). To evaluate the relationship between absolute value symmetry index from the isometric leg press and for peak VGRFs during landing, a Pearson product moment correlation was used. Finally to determine if leg dominance is related to asymmetry of timing of impact, Phi correlations for dichotomous variables were used. Two correlations were conducted: one utilizing the common definition of dominance as the 'leg with which you kick a ball', and a second correlation in which dominance is determined as the leg with the greatest value in at least two of three trials of the isometric leg press test. All statistical tests were evaluated for significance using an alpha of $p \leq 0.05$.

CHAPTER IV: Results

The purpose of this study was to examine the relationship between asymmetries in GRFs in a drop-landing task and isometric strength test in healthy adults. Four symmetry indices were used to determine if a relationship exists between the two variables: absolute symmetry index of the dominant leg for peak isometric force (SIKI), symmetry index of the stronger leg for peak isometric force (SISI), absolute symmetry index of the dominant leg for peak landing force (SIKL), and the symmetry index of the stronger leg for peak landing force (SISL). The dominant leg was defined as the subject's preferred leg to kick a ball, while the stronger leg provided the greatest peak force value in either the strength test or drop-landing task. This chapter will report the results of the statistical analyses as well as the descriptive statistics of the subjects who participated in this study.

Demographics

Our study consisted of 16 (10 male, 6 female) students from Eastern Washington University. One male subject was not included in the statistical analyses due to the loss of data for the isometric leg press test. The mean and standard deviation (SD) for age of all subjects was 23.5 yrs \pm 3.4. The means and SDs for the height and weight for all subjects were 176.6 cm \pm 10.3 and 191.1 lbs \pm 44.2 respectively.

Statistical Analyses

A Cronbach's alpha was used to test the reliability of each trial. All tests met Cronbach's alpha ($\alpha > .70$) for intrasubject reliability: relative left leg isometric peak force ($\alpha = .98$), relative right leg isometric peak force ($\alpha = .99$), relative landing left leg

Table 1

Sharpio-Wilk Tests of Normality for mean data

Variable	Statistic	df	Sig.
RpfLm	.955	15	.600
RpfRm	.907	15	.124
RlmfLm	.842	15	.014*
RlmfRm	.904	15	.109

Note. RpfLm = relative isometric peak force left leg mean, RpfRm = relative isometric peak force right leg mean, RlmfLm = relative landing peak force left leg mean, RlmfRm = relative landing peak force right leg mean

*Significant at ($p < .050$)

peak force ($\alpha = .92$), and the relative right leg peak force ($\alpha = .83$). The one way-ANOVA served to test for trends in trials. All one-way ANOVAs were not significant across trials for any variable ($p > .05$). Because all tests were reliable, the trials were collapsed across for further statistical analyses. A Shapiro-Wilk test of normality was analyzed on SPSS™ for mean values (relative to bodyweight) of isometric strength and VGRFs. Only 1 variable did not meet a normal distribution (refer to table 1). The results also suggested that one subject was an outlier. Furthermore, all tests were run both with and without the outlier to determine whether the subject's data would make a significant difference to the results. No significant differences were noted, so all of the following data are reported with all of the subjects.

Prior to testing for the research hypotheses, independent t-tests were used to determine if there was a sex effect with both symmetry indices (the stronger leg, and the leg the subject declared as the dominant leg). The SIKI showed no significant difference between males and females ($p = .330$). The SISI also suggested no significant difference between sex ($p = .884$). Likewise, there was no significant difference between males and females in VGRFs in drop-landing: SIKL ($p = .741$), SISL ($p = .789$). Because there was no sex effect in the data all other results were collapsed across sex for subsequent evaluation of the research hypotheses.

The second analyses performed were one sample t-tests comparing the absolute value symmetry index for each variable to a value of zero. The one-sample t-test was used to evaluate whether the limbs were symmetrical with regard to force production, with the comparison value of zero indicating symmetry. All statistical values were significant: SIKI ($t_{(14)} = 3.390, p = .004$), SISI ($t_{(14)} = 2.959, p = .010$), SIKL ($t_{(14)} =$

6.619, $p < .001$), SISL ($t_{(14)} = 6.472$, $p < .001$). All values indicated a significant difference in both isometric force production in the leg press test and peak force in a landing task meaning there are asymmetries present in the lower extremities for isometric strength and VGRFs in drop-landing.

Pearson product moment correlations were used to evaluate the relationship between the absolute value symmetry index from isometric leg press and VGRFs in drop-landings (refer to table 2 and 3 for symmetry indices). The Pearson correlation for SIKI and SIKL ($r = .133$) showed no significant relationship between the two variables. Likewise, SISI and SISL ($r = .165$) demonstrated no significant difference. These data indicated that there is no relationship between strength asymmetries and VGRF asymmetries in landing.

The final analyses that was calculated on SPSS™ were phi correlations to determine if leg dominance is related to asymmetry on time of impact. The statistical analyses revealed no significant association between the first leg to land in the drop-landing task and the SISI ($r = .077$). There was also no significant association between the first leg to make impact on the drop-landing task and the SIKI ($r = -.320$). The correlation revealed no association between strength asymmetries and impact time in landing.

Table 2

Isometric Mean Raw Data Relative to Bodyweight and Symmetry Indices

RpfLm	RpfRm	SIKI (%)	SISI (%)
1.733	1.617	7.17	6.69
1.029	1.101	6.49	6.49
1.438	1.533	6.18	6.18
2.759	2.462	12.04	10.75
2.601	2.701	3.87	3.72
2.204	2.081	5.88	5.55
2.175	2.567	18.03	45.98
2.904	2.843	2.13	2.09
2.312	2.331	.80	.80
2.731	2.589	5.46	5.18
3.000	2.990	.34	.34
1.353	1.330	1.78	1.74
1.575	1.292	21.89	17.96
2.330	2.358	1.20	1.20
1.832	1.358	34.82	25.83

Note. RpfLm = mean relative isometric peak force left leg, RpfRm = mean relative isometric peak force right leg SIKI = symmetry index percent for the preferred leg to kick a ball an isometric force production, SISI = symmetry index percent for the stronger leg an isometric force production

Table 3

Landing VGRFs Mean Raw Data Relative to Bodyweight and Symmetry Indices

RlmfLm	RlmfRm	SIKL (%)	SISL (%)
1.342	1.600	16.11%	16.11%
3.799	3.121	21.70%	17.83%
1.811	1.979	8.51%	8.51%
1.872	1.975	5.23%	5.23%
2.952	3.166	7.27%	6.77%
1.698	2.485	31.69%	31.69%
1.825	2.228	22.09%	18.09%
1.330	1.931	31.16%	31.16%
2.334	2.519	7.32%	7.32%
2.049	1.689	21.29%	17.55%
1.746	1.684	3.66%	3.53%
2.141	2.031	5.44%	5.16%
1.641	2.105	22.05%	22.05%
3.308	2.736	20.94%	17.32%
1.703	2.007	15.14%	15.14%

Note. RlmfLm = mean relative VGRFs left leg, RlmfRm = mean relative VGRFs right leg SIKI = symmetry index percent for the preferred leg to kick a ball in drop-landing VGRFs, SISI = symmetry index percent for the stronger leg in drop-landing VGRFs

Chapter V: Discussion

The objective of this study was to identify the differences between the dominant and non-dominant limbs in both isometric strength and vertical ground reaction forces (VGRFs) in landing. In addition, this study examined whether or not the symmetry index of a drop-landing task would relate to the symmetry index of an isometric strength test in healthy adults. The results revealed a significant difference between dominant and non-dominant limbs, but no significant relationship between the symmetry indices in isometric strength and VGRFs in landing. The following text will interpret the results of the statistical analyses, compare the findings with previous literature, as well as discuss potential sources for the results.

Bilateral Strength and Landing Correlation

The primary purpose of this study was to observe whether there would be a significant relationship in bilateral strength and landing differences. Two statistical tests were analyzed on SPSS™ to determine whether to accept or reject the null hypothesis.

Both the Pearson and phi correlation were not significant. Previous literature investigated the relationship between the strength and landing task and reported similar results, however using different methodologies (Beutler et al., 2009; Carcia et al., 2011; Mizner et al., 2008).

Carcia and colleagues (2011) found no significant relationship with asymmetries in force production for the isometric leg press test and VGRFs in unilateral drop-jump landings off of a 40 cm box. They concluded that perhaps if they used a more functional strength test they would be able to reveal a significant relationship to strength and landing

asymmetries. The 5-hop test is one functional assessment that has been used to investigate bilateral strength asymmetry in the lower extremities (Newton et al., 2006). Their report found significant strength asymmetries between the limbs. The test involves an individual to complete four consecutive hops on one leg followed by one hop on both legs. The objective for each individual is to maximize total distance (Newton et al., 2006). The 5-hop test is much more similar to a landing task than a maximal voluntary isometric contraction and therefore it may be a more applicable test when investigating asymmetries in drop-landings. Thus, future studies should consider the use of more functional strength test to investigate the relationship of asymmetries in drop-landings.

Another study examined strength and landing differences, but their objective was to determine whether there was a relationship between strength asymmetries and lower extremity kinetic and kinematic variables in landing after instructions were given to correct improper technique (Mizner et al., 2008). They found no difference in the relationship between strength and change in landing kinetics and kinematics after instruction. Their study, although very different from ours, also found low to no correlations in muscle strength values and percent change in landing after instructions were given to subjects. The study of Mizner and colleagues also used an isometric test for strength. This further supports that the use of a more specific strength test might be more appropriate. A similar study assessed lower extremity force production to landing technique and did not find a significant relationship between the two tasks (Beutler et al., 2009). The main purpose of this study was to observe jump-landing using the LESS score (a 17-point observation test that evaluates landing technique based on landing errors) and determining whether there was relationship to lower extremity strength. Out the of the

six lower extremity strength variables that were test using an isokinetic dynamometer only one was significant ($p = .05$). Even though this study used a score that subjectively described the landing of 2,734 individuals with the use of the LESS score their results were similar to the non significant results discovered in our study. Thus, the LESS score demonstrated similar results to quantitative data when examining the relationship of strength to a drop-landing task.

Landing Asymmetry

There were significant differences in SIKL and SISL indicating that there was a considerable difference between the lower limbs in VGRFs. A previous study supported these findings within subjects for drop-landings (Schot et al., 1994) whereas another study did not report significant differences (Ball & Scurr, 2009). Schot and colleagues (1994) discovered that 4 out of every 5 subjects were predisposed to landing on one side during drop-landings at 60 cm height. On the contrary, no significant differences in peak VGRFs were found when using bounce drop jumps in subjects (Ball & Scurr, 2009).

Ball and Scurr (2009) reported ($t_{(14)} = -0.8, p = 0.432$) the differences of the lower extremity in peak resultant forces and their analysis did not distinguish between leg dominance, but the inherent differences in the right and left leg. Hence, it is important to define leg dominance when observing bilateral asymmetries. Moreover, the bounce drop jump task is different from a bilateral drop-landing. Overall, only a few studies have analyzed the differences in VGRFs in bilateral asymmetries and should be further explored through research.

Strength Asymmetry

The SISI and SIKI were both significant when examining the bilateral asymmetry data thus, indicating that there are significant differences in the dominant and non-dominant limbs in healthy adults. There has been much controversy within the literature whether or not strength asymmetries are present in the lower extremities (Bennell et al., 1998; Grace et al., 1984; Newton et al., 2006; Oshita & Yano 2010; Yamamoto, 1993). Yamamoto (1993) discovered bilateral differences on two of six isometric tests when using a symmetry index on subjects' data relative to body weight. Their symmetry index for dominance was based on the leg that had higher force production in the isometric strength tests. The research revealed bilateral differences between 7-14% in six different isometric measures. Furthermore, the two significant asymmetries reported were hip flexion and knee extension movements, possibly explaining why our study also revealed a significant difference in our isometric strength test (classified as a knee extension movement). It is important to note that Yamamoto (1993) used a between-subjects design when comparing hamstring strain to non-strain athletes, which could contribute to the inconsistency in significant findings. Another study used the SISI and identified asymmetrical differences in as low as 30% maximal voluntary contraction (MVC) (Oshita & Yano, 2010). Significance was discovered in an isometric flexion and extension task. Our study used an extension leg press task that supported these findings at 100% MVC. The similarities in these results support that bilateral strength asymmetries do exist in healthy populations, at least when assessed isometrically.

Newton and colleagues (2006) investigated the bilateral strength difference in dominance, but with the use of isokinetic and functional tests. The researchers found a

significant difference of 6%, but could not find a difference between the right and left lower extremity. This study agrees with the previous notion that future studies examining bilateral asymmetry should identify the dominant and non-dominant limbs of the lower extremities before further analysis. Simply comparing the right and left limb does not help identify limb asymmetry, because previous research has supported that there are neuromuscular differences between the legs that occur before birth (Previc, 1991). Strength is one factor that is influenced during development of the lower extremities that may contribute to the asymmetries found in healthy individuals.

Grace et al. (1984) studied bilateral strength differences in knee-joint patients and could not identify any significant differences. The study found a third of the population to have more than 10% difference in bilateral differences, but leg dominance was not consistent with the occurrence on the side of leg dominance (Grace et al., 1984).

Although the study analyzed the occurrence of subjects that had an asymmetry of greater than 10%, they did not conduct appropriate any statistical analyses (such as a one sample t-test) to determine whether there was a significant difference. The lack of a within-subjects statistical test for SI leg dominance may be the reason why there was no significance identified in the population. Similar to the previous study mentioned, Bennell and colleagues (1998) examined injured athletes for bilateral strength differences using isokinetic testing except their definition of dominance was the preferred leg to kick a ball. The study also did not discover any differences within-subjects. In Bennell's et al. (1998) analysis there was no use of a symmetry index. If a symmetry index was used, the researchers may have discovered significant differences between the lower limbs. Overall, it seems that isometric testing was more consistent for evaluating bilateral

differences and that the proper statistical tests for the symmetry indices must be analyzed when investigating bilateral asymmetry.

Sex Effect

Comparing the difference between males and females was not a part of the original hypotheses for this study. Most of the previous literature found no significant difference in VGRFs in bilateral landing between males and females with the exception of one study (Kernozek et al., 2005). Therefore, an independent t-test was used to determine whether or not the primary statistical analyses could be collapsed across the sexes. There was no significant difference in SIKI, SISI, SIKL, and SISL meaning that males and females shared the same symmetrical characteristics in both the isometric strength test and VGRFs in a bilateral drop-landing task. Multiple studies that have analyzed VGRFs supported that there were no significant differences when comparing males and females in a drop-landing task (Cortes, 2007; Decker et al., 2003; Lephart et al., 2002; Paterno et al., 2011). Cortes (2007) examined drop-jump landings from 30 cm in healthy volunteers. The researchers observed no significant differences in peak VGRFs in both forefoot and rear foot landings. Cortes et al. (2007) suggested that there was no VGRF differences due to the simple landing pattern from a box. Our study involved subjects from a hanging position and therefore there may not be a significant difference in methodology when examining sex differences in VGRFs in bilateral landing tasks.

Decker et al., (2003) revealed no significant differences in any VGRF variables when analyzing 60 cm drop-landing across sexes. First and second peak forces were analyzed relative to body weight in their analysis. The statistical analysis was similar to

our study because relative scores were used to analyze data for the drop-landing task. Thus, drop-landings from 30 cm to 60 cm may be similar between sex when observing VGRFs.

Similarly, one study examined whether there would be VGRF differences between males and females in a drop-landing task with forefoot and rearfoot landing techniques, but used unilateral landing in subjects (Lephart et al., 2002). Neither landing technique had a significant difference between sex. Their study used the SIKL for VGRFs and agreed with our findings. Paterno and colleagues (2011) also investigated the sex effect on VGRFs when observing rehabilitation patients after anterior cruciate ligament (ACL) surgery and the researchers did not identify significant results ($p = .999$). It appears that whether the population is injured or non-injured, there does not seem to be a difference between males and females with regard to peak VGRF (relative to bodyweight).

In contrast, other studies discovered sex differences in VGRFs in drop-landings (Kernozek et al., 2005; Kernozek et al., 2008). Both studies used drop-landings from 50-60 cm height however, one study examined singled-leg landings. The single-leg landing study reported an 8% higher peak of VGRF in women compared to men. Subjects in these studies were instructed to have their feet flat so that they would land flat on the force plates. These instructions contrasted from previous studies that examined sex differences in VGRFs and may be the reason why there is a discrepancy in the data analysis. Perhaps, future studies comparing sex differences, should observe initial foot positioning of subjects in a hanging position for drop-landings.

Leg Dominance

In our study two symmetry indices were used to compare our results to previous literature. Some studies define the stronger leg as the dominant lower limb whereas other studies referred the dominant leg as the preferred leg to kick a ball. In the statistical analyses there was no difference between the symmetry index in both definitions that were used. It is possible that there may be no difference in the two definitions for analyzing bilateral asymmetry when using a symmetry index measure.

Conclusion

In summary, this study did not reveal any relationship between strength and bilateral drop-landing asymmetries. Other similar studies reported similar results. Perhaps, an isometric strength test is not the best procedure when analyzing the relation between the two variables. Future studies should use functional testing other than the isometric leg press to investigate the relationship between strength and landing asymmetries. Second, asymmetries were present in both isometric strength and drop-landing tasks no matter what symmetry index was used. Some studies in the past have not found strength asymmetries with the use of isokinetic testing, hence isometric strength test may be better in examining bilateral asymmetries. Finally, future studies can use either definition of leg dominance as long as a symmetry index is used to analyze data for bilateral symmetry.

APPENDIX

Questionnaire for Participation in Research Study

Name of subject: _____

Age: _____

Please describe the physical activities you engage in each week:

Please explain anytime you experienced an injury to any part of your lower extremities (ankle sprain, knee injury, etc...):

Describe any current illnesses you may be suffering from:

You will be asked to hang briefly from your hands, holding onto a set of gymnastics rings. Do you have any current or prior injuries which may limit your ability to perform this task?

Would you prefer kicking a soccer ball with your left or right leg?

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